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Energy Efficiency Improvement Solutions for Supermarkets by Low-E Glass Door and Digital Semi-Hermetic Compressor

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Abstract: This research presents an energy efficiency improvement solution for supermarkets with the use of low-E glass doors for open refrigerators and a digital semi-hermetic compressor to fix the speed of semi-hermetic compressors. The impact of a door's installation causes its load to be reduced by 40%, and the compressor shuts down frequently, which decreases its lifetime. In order to ensure that energy-saving solutions do not affect maintenance costs, the installation of a digital semi-hermetic compressor is proposed to lower costs and save energy. Our economic results from tests carried out at a 3000 square meter supermarket, which was open from 6:00 a.m. to 12:00 a.m. and in which we installed 82 doors on 15 open refrigerators, showed a 1.1-year payback period with an energy saving rate of 192,220 kWh/year for store No.1 (R22) and in which we installed 80 doors on 15 open refrigerators, showed a 1.4-year payback period with an energy saving rate of 171,185 kWh/year for store No.2 (R404A). The energy-saving effects of the digital semi-hermetic compressor, which fixes the speed of the semi-compressor and solves the problem of impact from fridge door installation, showed a 2.9-year payback period with an energy saving rate of 26,890 kWh/year for store No.1 (R22) and showed a 2.9-year payback period with an energy saving rate of 26,571 kWh/year for store No.2 (R404A). The results of store No.1 (R22) and store No.2 (R404A) showed no differences. This research is an extension of an energy-saving project that can be carried out on a continuous basis, increasing the efficiency of energy use and being a sustainable source of energy conservation.

Keywords: low-E; digital compressor; energy efficiency

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1. Introduction

The domestic sector's energy consumption has the second-highest power consumption rate in Thailand [1]. Retail businesses, which are part of the business sector, continue to grow in response to consumer behavior [2]. Currently, there are more than 2000 supermarkets in Thailand. Most energy consumption in supermarkets comes from refrigeration; thus, a way to reduce energy consumption can be achieved through energy management or the use of high-performance equipment. Most freezers at supermarkets are open freezers so that consumers can see products clearly and access them easily [3,4]. Typically, freezers are designed to provide a strong air curtain in order to maintain low temperatures and control product quality. [5,6]. The air curtain principle, with the front widow making up 80% of total air volume, is responsible for maintaining the temperature of supermarket refrigerators [7,8]. The remaining 20% is the air supply that comes from the back wall inside the refrigerators, and which is responsible for lowering the temperature of the product [9,10]. All winds are combined to return air below [11,12]. Open freezers are affected by a number of external factors that result in heat loads entering the freezer [13,14]. The inefficiency of the air curtain impacts the compressor and increases energy consumption [15,16]. The development of open freezers is still ongoing, but it does not solve the problem of external factors, as expected [17,18]. There are many factors which affect the efficiency of open refrigerators, such as the following: (1) Normally, open refrigerators require a temperature of 25 °C in the store and 60% humidity; (2) the wind of an air conditioner that blows into a refrigerator will reduce the efficiency of its air curtain; (3) customers picking products from inside the cabinet also reduce the efficiency of the air curtain; (4) as does the replenishment of goods by staff; and (5) something obstructing the returned air [19,20]. All of these uncontrollable factors affect the efficiency of the air curtain and directly affect compressor energy consumption [21,22]. This research presents the installation of an energy efficiency improvement solution in supermarkets by the use of a low-E glass door and a digital semi-hermetic compressor to solve the abovementioned uncontrollable factors [23,24]. In addition to being able to maintain its temperature, a closed freezer can control the temperature of an open freezer, and can also help ensure that products do not exceed five degrees Celsius, which is where germs are formed [25,26]. The results of this research will contribute to sustainable energy reductions and the maintenance of quality products for customers [27–30].

2. Materials and Methods

2.1. Low-E Glass Door

Low-E glass is low heat transfer glass used in buildings [31,32]. Low-E glass is applied to doors and windows to enable buildings with low heat transfer to take advantage of the light coming from outside. Low-E glass was developed to reduce heat transfer by replacing the coating material or replacing the material used in the production of glass films [33,34]. Additionally, it has been developed using double layers, or more glass, to reduce heat transfer [35,36]. The gaps between the glass can also be used to provide insulation by increasing the air gap or adding gases to increase efficiency [37,38]. This research applied low-E glass for doors to be installed in open freezers in order to reduce the uncontrollable factors that can occur with open freezers [39,40]. In this research, two-layer glass was used and argon gas was added to increase efficiency [41,42]. Due to the glass comprising three layers, the size of the door was thick, but the price of argon gas was cheap [43,44]. The 15 open refrigerators in question were equipped with 82 additional doors for store No.1 (R22) and the 15 open refrigerators in question were equipped with 80 additional doors for store No.2 (R404A) [45,46], as shown in Figure 1. The door design must suit the size of the refrigerators, and a strong support part must be designed to support the weight of the door and customer use, as shown in Figures 2 and 3 [47,48].

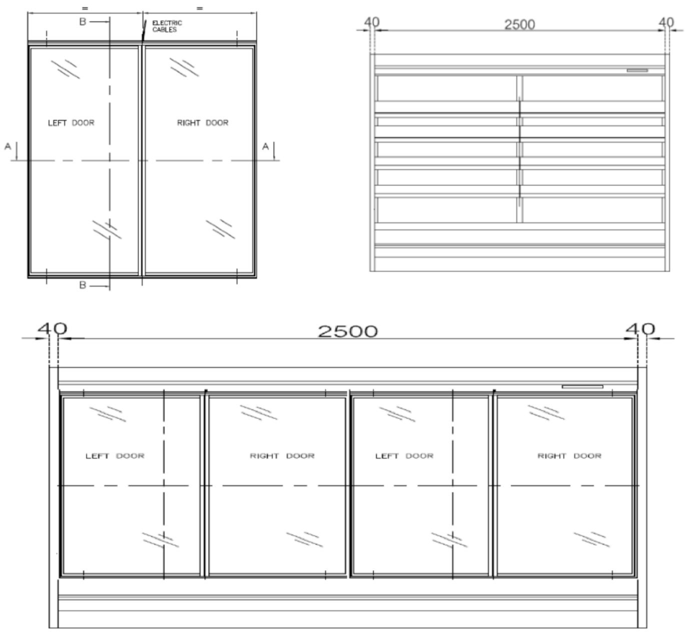

Figure 1. Low-E glass door design.

Figure 2. Installation of Low-E glass door for store No.1 (R22).

Figure 3. Installation of low-E glass door for store No.2 (R404A).

2.2. Digital Semi-Hermetic Compressor

Digital compressors are compressors that can be adjusted during operation in order to suit cooling needs. They were developed as scroll compressors for use in air conditioners [49,50]. A digital semi-hermetic compressor can reduce the duty cycle to suit the current load while, in the unloaded state, not sucking or compressing the refrigerant, resulting in a 50% reduction in compressor energy consumption [51,52]. As for the air conditioner, it can be adjusted according to room temperature. For air conditioners, the cycle can be adjusted according to room temperature by calculating from room temperature and suction pressure, as well as other parameters [53,54]. For refrigeration systems, the cycle can also be adjusted according to room temperature by calculating from room temperature and suction pressure or other parameters [55,56]. However, in supermarkets with high cooling requirements in medium-temperature environments, semi-hermetic compressors are usually used, as shown in Figures 4 and 5. This research proposes energy savings and solves the problem of door installation impacts by the use of compressors, thus reducing frequent compressor cut-offs [57,58]. The result will not only help prolong the service life of the compressor, but will also help to save energy at a specified standard temperature [59,60].

Figure 4. Digital compressor rack with digital compressor and digital controller No.1 (R22).

Figure 5. Digital compressor rack with digital compressor and digital controller No.1 (R404A).

The results of this research were summarized and correlated before and after 7 days using energy and temperature meters with the following parameters: power consumption (W), voltage (V), current (I), power factor (PF), and frequency (Hz). In terms of energy consumption, pre- and post-energy consumption is summarized. Over seven days, we compared the highest and lowest energy consumptions, as separated by day and night. In order to see differences in energy consumption during the closed branch period, average hourly energy consumption was summarized to illustrate consumer behavior. In terms of thermodynamic properties, temperature was measured by the following metrics: temperature (Tev), condenser temperature (Tcd), liquid temperature (Tl), sub cool temperature (Tsc), gas temperature (Tg), and superheat temperature (Tsh). A compressor operation percentage (%) was used to compare compressor action before and after the 7-day period. The compressor design point was at −10 °C evaporator, condensate temperature was at 40 °C, and superheat temp was at 25 °C [61–63].

3. Results

3.1. Energy Efficiency Improvement by Low-E Glass Door

As shown in Figure 6, the results of the power consumption measurement/day, both before and after low-E glass door installation, show that the energy consumption of the average 7-day refrigeration system before door installation was 1388 kWh/day, which is divided into 997 kWh/day in the day (06:00 a.m.–10:00 p.m.) and 391kWh at night (10:00 p.m.–06:00 a.m.). The energy consumption of the average refrigeration system after low-E glass door installation was 812 kWh/day, which is divided into 579 kWh/day during the day (06:00 a.m.–10:00 p.m.) and 233 kWh at night (10:00 p.m.–06:00 a.m.). The seven-day average total for energy efficiency was 576 kWh/day, or 39.67%, which is divided into a day time consumption of 418 kWh/day, or and 41.93%, and a night time consumption of 158 kWh/day, or 33.24% for store No.1 (R22). As shown in Figure 7, the seven-day average total for energy efficiency was 469 kWh/day, or 37.37% for store no.2 (R404A). The energy savings during the day are greater than at night due to uncontrollable factors during the day. Moreover, prior to installing the low-E glass door, many supermarkets were using plastic curtains at night. The results of store No.1 (R22) and store No.2 (R404A) showed no differences.

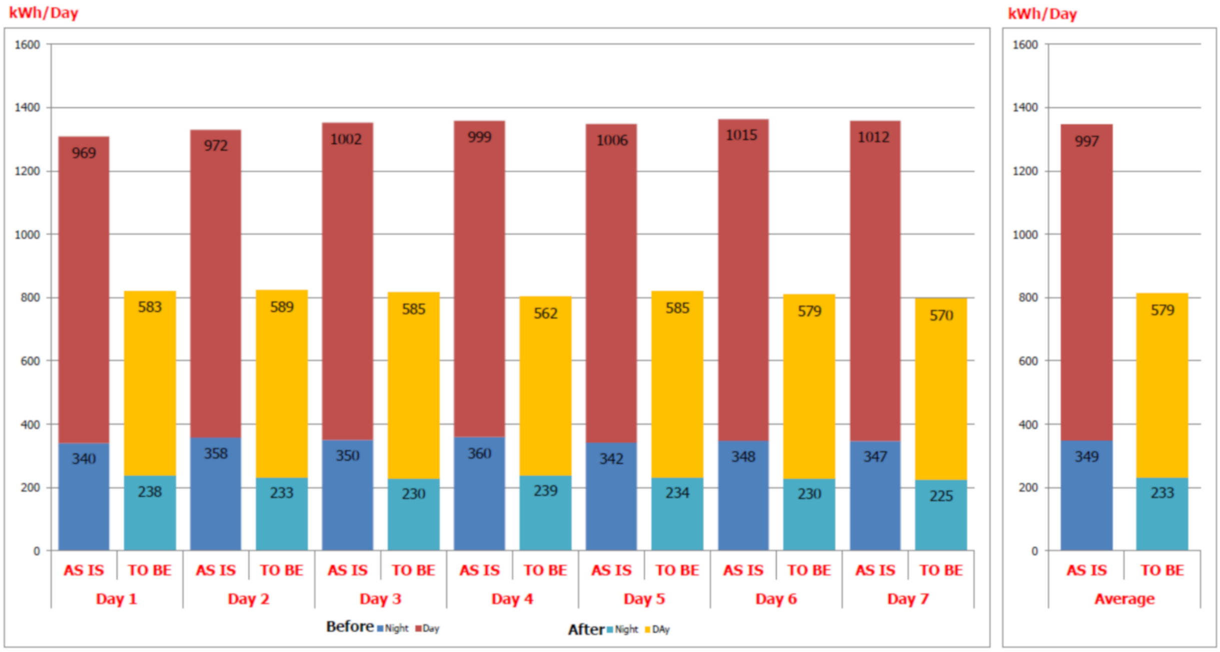

Figure 6. Average power consumption per day before and after door retrofits for store No.1 (R22).

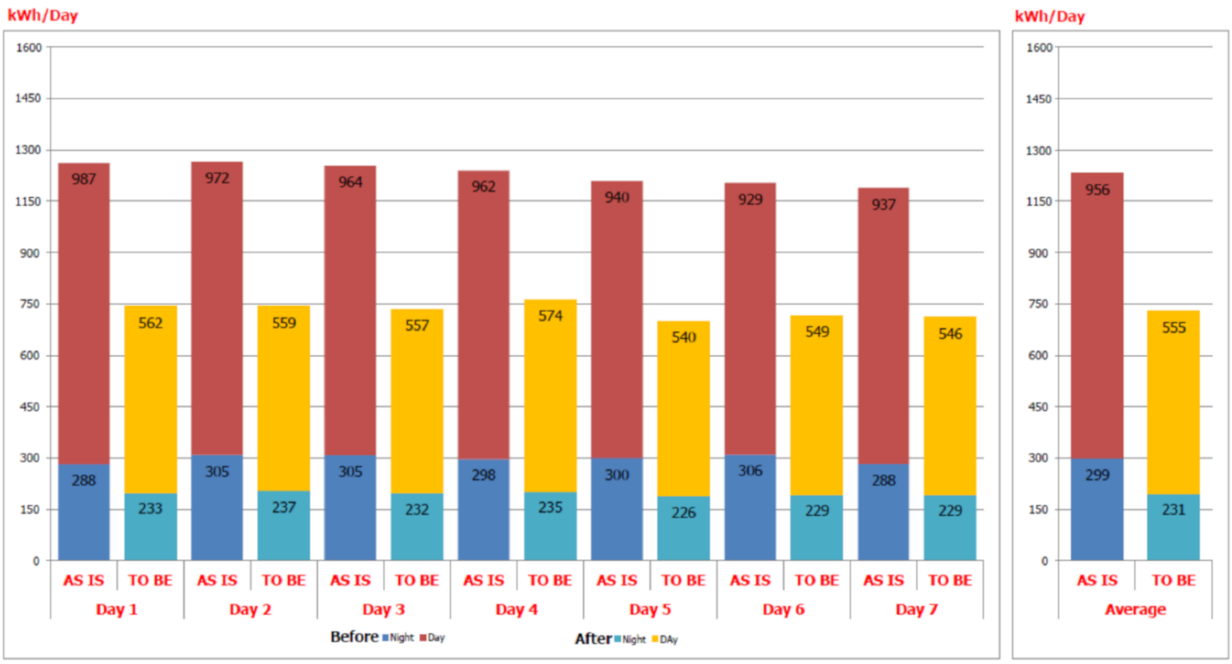

Figure 7. Average power consumption per day before and after door retrofits for store No.2 (R404A).

As shown in Figure 8, the maximum and minimum energy consumptions before door installation were 83.25 kW and 44.73 kW, respectively, showing a difference of 46.72%. After installing the door, Figure 9, the highest and lowest energy consumptions before door installation were 33.15 kW and 30.19 kW, respectively, showing a difference of 8.93%. Installing the door led to a reduction in uncontrolled external factors during the day and at night, but a smaller difference in energy consumption was observed, meaning that energy can be saved. Economic results from testing at a 3000-square-meter supermarket, which was open from 6:00 a.m. to 12:00 a.m. and in which we installed 82 doors on 15 open refrigerators, showed a 1.1-year payback period with an energy saving rate of 192,220 kWh/year for store no.1 (R22). As shown in Figure 8, results showed a 1.3-year payback period with an energy saving rate of 171,185 kWh/year for store no.1 (R22).

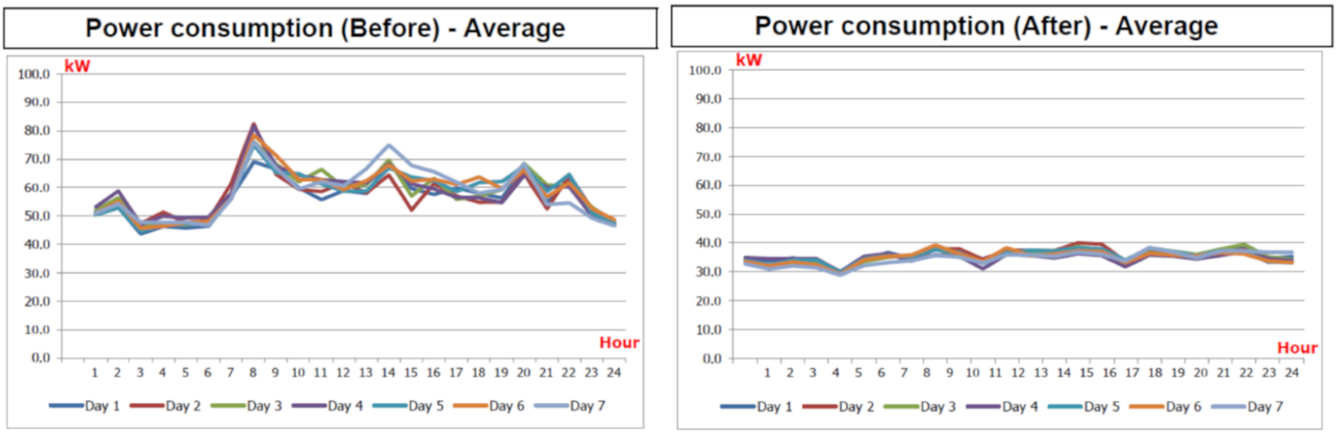

Figure 8. Average power consumption per hour before and after retrofits for store No.1 (R22).

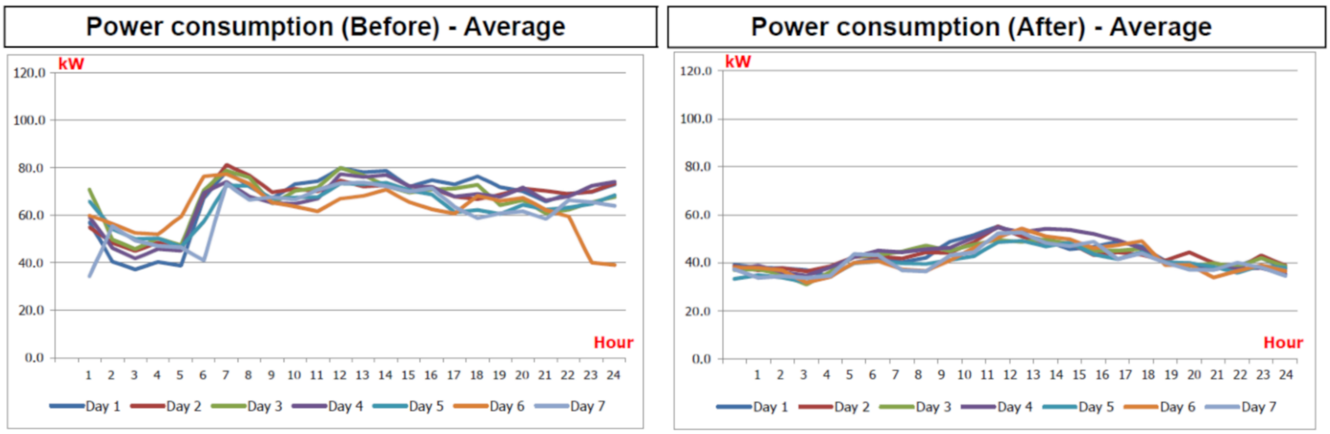

Figure 9. Average power consumption per hour before and after retrofits for store No.2 (R404A).

3.2. Energy Efficiency Improvement by Digital Steam Compressor

The impact of the door installation results in the compressor stopping and starting frequently, which, in turn, reduces its life. From the effect of temperature against the operating status of the compressor, as shown in Figure 10, it was found that the compressor is stopped by the pump down method, resulting in the evaporator temperature lowering to −20 °C. This is much lower than the design point of −10 °C, as the compressor was stopped many times due to excessive work.

After installing a digital compressor, the digital semi-hermetic compressor reduced the duty cycle to suit the current load, as shown in Figures 11 and 12, while, in an unloaded state, the compressor did not suck or compress the refrigerant, resulting in a 50% reduction in compressor energy consumption. The compressor was operated with a pressure converter that converts pressure from suction pressure to evaporator temperature. At the design point, the controller can set a setpoint to control compressor operation in both a loaded and an unloaded state. From the effect of temperature against the operating status of the compressor, it was found that digital compressors could maintain their operation at −10 °C degrees while operating in an unloaded state, resulting in reduced overload and frequent stop-and-start problems. The energy saving effect of digital semi-hermetic compressors on fixing the speed of semi-compressor installation showed a 2.9-year payback period with an energy saving rate of 26,890 kWh/year for store No.1 (R22) and showed a 2.9-year payback period with an energy saving rate of 26,571 kWh/year for store No.2 (R404A). These energy saving results can be compared with previous research, as shown in Table 1. The results of energy use are consistent with and close to previous studies, and differences in the research depend on actual use conditions.

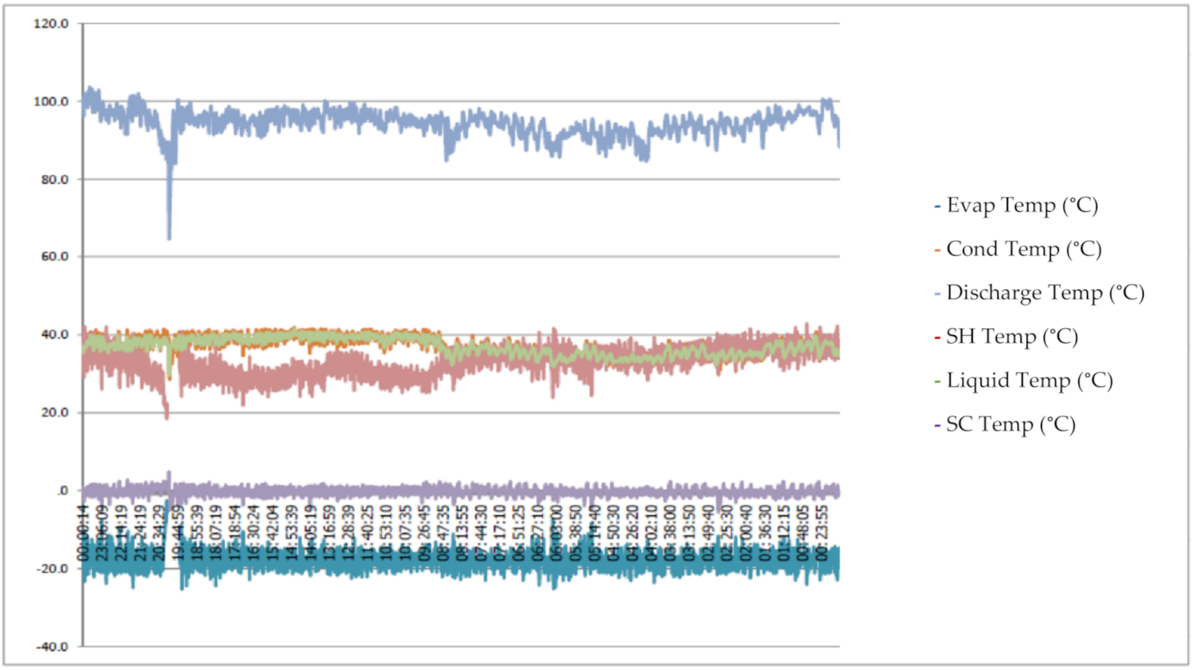

Figure 10. Temperature result for the fixed-speed semi-hermetic compressor.

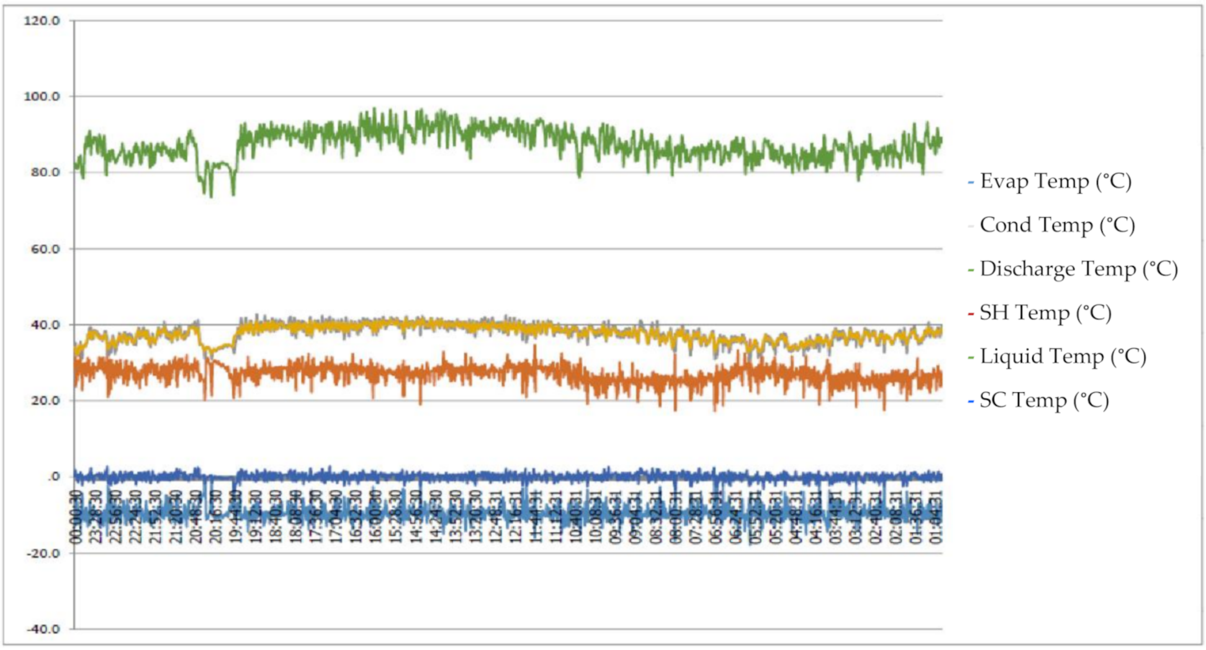

Figure 11. Temperature result for the digital-speed semi-hermetic compressor.

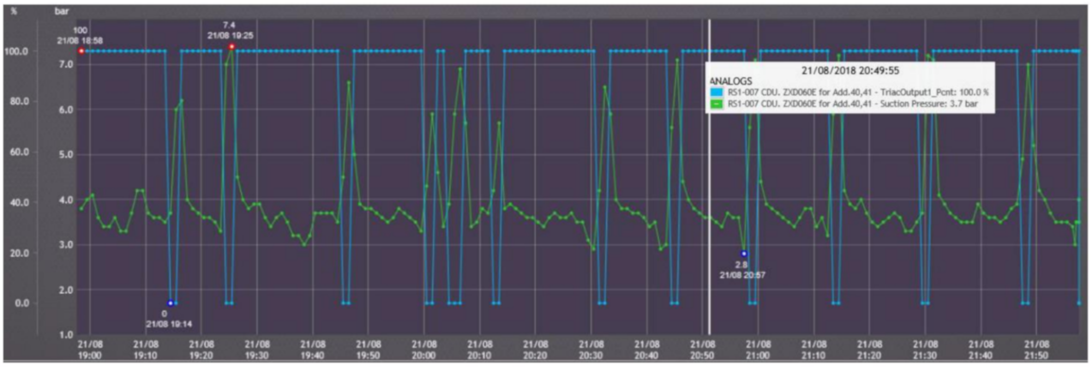

Figure 12. The operating status for the digital semi-hermetic compressor.

Table 1. The energy savings compared with previous research.

Open Refrigerated with Doors		Digital Scroll Compressor	
Previous Research	**Energy Saving (%)**	**Previous Research**	**Energy Saving (%)**
Wu et al. (2015)	20–30%	Cha, Kwon, and Oh (2014)	26.70%
Chaomuang et al. (2019)	20–70%	Pattana, Tantakitti, and Wiratkasem (2020)	20%
Chaomuang et al. (2020)	23–73%	Saengsikhiao et al. (2020)	34%
Xie et al. (2021)	69%	Present Study No.1 (R22)	19%
Present Study Store No.1 R22	39.67%	Present Study No.2 (R404A)	24%
Present Study Store No.2 R404A	37.37%		

4. Conclusions

Installing doors in an open freezer not only reduces compressor energy consumption, but also reduces the effects of uncontrollable external factors. It helps to stabilize product temperature and maintain the quality of the product. The results from testing at a 3000-square-meter supermarket, open from 6:00 a.m. to 12:00 a.m. and in which we installed 82 doors on 15 open refrigerators, showed a 1.1-year payback period with an energy saving rate of 192,220 kWh/year for store No.1 (R22) and a 1.4-year payback period with an energy saving rate of 171,185 kWh/year for store No.1 (R404A). After the doors were installed, the operating load of the compressor was reduced and the compressor shut down frequently. Installing a compressor is another option that increases its service life, and it also reduces compressor energy consumption. The energy saving effects of the digital semi-hermetic compressor, which fixes the speed of the digital semi-compressor and solves the problem of impact from fridge door installation, showed a 2.9-year payback period with an energy saving rate of 26,890 kWh/year for store No.2 (R22) and showed a 2.9-year payback period with an energy saving rate of 26,571 kWh/year for store No.2 (R404A). The results of store No.1 (R22) and store No.2 (R404A) showed no differences. This research is an extension of an energy-saving project that can be carried out on a continuous basis, increasing the efficiency of energy use and being a sustainable source of energy conservation.

Author Contributions: Conceptualization; Software; Validation; Formal Analysis; Investigation; Resources; Data Curation; Writing—Original Draft Preparation; Writing—Review and Editing, P.S.; Visualization; Supervision; Project Administration; Funding Acquisition, J.T. All authors have read and agreed to the published version of the manuscript.

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